The Saturn Rocket

and the

Pegasus Missions,

1965

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Introduction

The story of the Saturn rocket is the story of rocket development, started in Germany, and lasting through World War-II. It was then continued both in the United States and the then-Soviet Union by members from the German teams. The driver was now not war, but political and world prestige. The story of the Saturn-V moon rocket starts with the V-2 missile development and continues through the Redstone, Jupiter, and the Saturn-1 rockets. The Saturn-1/Pegasus missions taught us a lot about the near-Earth micrometeorite environment, and confirmed the feasibility of the lunar missions.

The Saturn vehicles were developed by the von Braun team at Marshall Space Flight Center, formally the Army's Redstone Arsenal, in Huntsville, Alabama. Von Braun and his team of scientists and engineers had been brought to the U.S. by the Army after World War II ended. The rocket program was kicked off during the early post-World War-II Cold War era by President Eisenhower. At the time, the United States was in a race to space, and particularly, a launch vehicle race, with the Soviet Union. Each U. S. military service, the Army, Navy, and Air Force were developing their own rockets. Inter-service rivalry was finally squashed by Secretary of Defense Charles Wilson, who decided in November of 1956 to make the Air Force the primary missile developer for long range ballistic and space missions. The specifications for a heavy-lift vehicle were developed by the Advanced Research Projects Agency (ARPA).

The Army found a loophole in Wilson's decision. His edict applied to weapons systems, so the Army Ballistic Missile Agency (ABMA), founded in 1956 at the Redstone Arsenal, decided to pursue non-military space launches. The only way to achieve the heavy lift required was to use a cluster of proven, off-the-shelf engines, from earlier vehicles like the Redstone and Jupiter. These rockets had also been developed by the von Braun team at ABMA. The "Super-Jupiter" (Saturn) solved the Stage-1, getting-off-the-ground, problem in an evolutionary fashion, building upon proven components, designs, and procedures.

The formation of NASA in 1958 for pursuing civilian uses of space provided a framework to address the lunar mission, a high-visibility project to demonstrate the superiority of American technology to the world, kicked off by President Kennedy.

President Kennedy said the Saturn-I represented the first time the U. S. lift capability to orbit exceeded that of the Soviets, in a speech at Brooks AFB in San Antonio, Texas. He was assassinated in Dallas the next day, and did not get to see his project completed. The Saturn represented one of the first launch vehicles not to be designed specifically for military purposes. As a follow-on to the previous Jupiter rocket, and since Saturn is the next planet beyond Jupiter in the solar system, it got its name. There was no follow-on heavy lift vehicle beyond Saturn, as NASA chose to develop the mostly-reusable Space Transportation System (Shuttle).

As part of the development of the Saturn-V moon rocket, the Saturn-I vehicle was developed. There were a series of ten successful flights of this vehicle. The second stage became the Saturn-

V's third stage, and a new massive booster was developed for the first stage. But these initial ten flights to Search orbit validated the systems design, testing, and procedures for the later vehicle. The Saturn-I's later provided a way to Earth orbit for the Skylab and Apollo-Soyuz projects. This is the story of the last three test flights of the Saturn-I, missions SA-8, -9, and –10. These carried to Earth orbit not only the test version of the Apollo capsule, but also a big winged satellite to return data on the feared micrometeroid environment of near Earth. Not much was know about this, and early satellites had returned minor data. If the Apollo capsule with astronauts on board was to be penetrated by high speed objects in orbit and on its way to the moon, the mission was not feasible. A lot was riding on the data from Pegasus.

The Saturn I missions SA-8, -9, and -10 were used to launch the three Pegasus missions in 1965. The SA-8 and -10 vehicles were built by Chrysler Aerospace, with SA-9 built at the Marshall Space Flight Center (MSFC) in Huntsville. SA-10 was the last R&D flight for Saturn, with the next launch being considered the first operational one. The Pegasus flights used Saturn-I, block II vehicles, with two powered stages, and utilizing version 2 of the IU (instrument unit) for guidance. The guidance computer was the IBM ASC-15. SA-8 was the first Saturn flight with an operational payload, the previous missions being test flights of the vehicle itself. All three of the Pegasus missions left from launch pad 37B at Kennedy Space Center.

The Pegasus payload was intended to supply much-needed information on the near-space meteoroid environment, that would influence the design of manned spacecraft. The main reason this information was vital was that space missions were lasting longer, and getting bigger. They were puncture targets for small chunks of rock, smaller than a grain of sand, traveling faster than a bullet. Armor was out of the question – it would add too much weight. What were the chances of a meteorite hit, and how damaging would it be? No one knew.

These Saturn missions also provided valuable flight tests of Apollo hardware, test and validation of launch and staging procedures, as well as checkout and verification of guidance, control, telemetry, and command systems.

In this document, you will see both English and Metric (SI) units, as used in the referenced documents. By 1970, NASA had a requirement to use SI units exclusively, but this was frequently waived. This policy would lead to the loss of the Mars Climate Orbiter mission in September of 1999.

The author

Mr. Stakem has been interested in rockets and spacecraft since high school. Interested in modeling a Saturn-I vehicle, he wrote to the Marshall Space Flight Center, which replied with a box of drawings and documentation. He received a Bachelor's degree in Electrical Engineering from Carnegie-Mellon University in 1971, where he was a member of the Applied Space Sciences group. His first job was for Fairchild Industries, then building the ATS-6 spacecraft. Wernher von Braun joined Fairchild as Vice-President of Engineering during this time, so,

technically, Mr. Stakem was once a member of the von Brain Team. Specializing in support of spacecraft onboard computers, he has worked at every NASA Center. He received Master's degrees in Physics and Computer Science from the Johns Hopkins University. He has taught for Loyola University in Maryland, Graduate Department of Computer Science, AIAA, The Johns Hopkins University, Whiting School of Engineering, and Capitol College.

Saturn-I vehicle

All ten launches of the Saturn-I models from 1961 to 1965 were successful. The follow-on to the Saturn-I was the Saturn-IB, and the follow-on to that was the larger Saturn-V vehicle, required to achieve a trans-lunar trajectory. The Saturn IB had 9 successful launches, including the post-Apollo Skylab and Apollo-Soyuz missions. Saturn-V rockets were used for the 13 lunar mission launches. There were no failures of the Saturn vehicles in all of their flights, a tribute to the engineering prowess and attention to detail of the von Braun team.

The Saturn 1 was the first in a series of heavy lift rockets, leading to the Saturn-V. It could lift 9,000 kg to low Earth orbit (LEO) from launch complex LC-37 at the Kennedy Space Center in Florida. It was 180 feet long and 21.4 feet in diameter. The first flight was in October of 1961. The second stage, the S-IV, had six RL-10 engines, burning liquid hydrogen and liquid oxygen. A burn time of around 480 seconds could be achieved. Block–II vehicles were used in flights 6 through 10.

With the Instrument Unit, Apollo payload, and Launch Escape System (LES), the total vehicle configuration stood 57.3 meters tall, with a weight in excess of 1,130,00 lbs.

S-I first stage

There were eight engines in the Saturn first stage, Rocketdyne H-1's, with a sea-level thrust of 205,000 lbf each (for SA-206 and subsequent). The innermost four engines were placed with a cant angle of 3 degrees to the main axis. The outermost engines were gimbaled to provide steering control. The first stage was capable of lifting the vehicle to an altitude of some 90 kilometers, and downrange about 81 kilometers. The first stage guidance and sequencing of events was done by timer. Attitude control was maintained by swiveling the rocket engines using hydraulic actuators. The vehicle was aerodynamically unstable, so it required active control. Two sets of rate gyros were used. The gyro assemblies were each triple modularly redundant. Pitch and roll accelerometers were also used. The S-I stage measured 6.5 meters in diameter and 24.5 meters in length. It had a central Jupiter tank with LOX, and eight Redstone tanks clustered around it. The black tanks were for propellant, and the white tanks were for LOX. 41,000 gallons of RP-1 and 66,000 gallons of LOX were used. The ISP figure of merit for the engines was 289.

The H-1 engines were derived from the previous Redstone rocket. They burned liquid oxygen (LOX) and Rocket Propellant-1 (RP-1), a hydrocarbon-based fuel which was highly refined

kerosene. RP-1 was superior to the previously used alcohol fuels. The fuel in a liquid rocket engine is also typically used to cool the engines, a role that alcohol was superior at. The special formulation of RP-1 versus regular kerosene was also good as a coolant.

The first stage burned for some 150 seconds, achieving 1.5 million pounds-force. The engine could be fired multiple times, for instance, on a test stand before launch, but was not intended to be retrieved and reused. It was not re-startable in flight. A small solid propellant gas generator was used to get the big engine starting, by spinning up the turbopumps for fuel and oxidizer supply. One the rocket engine started, it was a self-sustaining process until the fuel ran out, or it was commanded to shut down. It had a peak burn time of 155 seconds. Fuel flowed at around 2100 gallons per minute, and oxidizer at 3300 gallons per minute. The combustion chamber pressure was 635 psi. After burnout, the first stage separated from the rest of the vehicle and fell into the Atlantic Ocean. They are still there.

After the vehicle was launched and cleared the tower, a stored program in the Launch Vehicle Digital Computer (LVDC) commanded the vehicle to roll about its long axis, and then to pitch to the desired azimuth. The sequence of events was controlled by a series of pulses on a 6-track tape recorder. These were pre-programmed values, based on ground calculations. The IU also controlled the time of the first stage engine cut-off and staging. This was based on a predetermined value of fuel in the tanks. This was essentially the same guidance system approach used in the V-2 rocket. Guidance during second stage burn also depended on a time sequence, but employed closed-loop adaptive guidance as well.

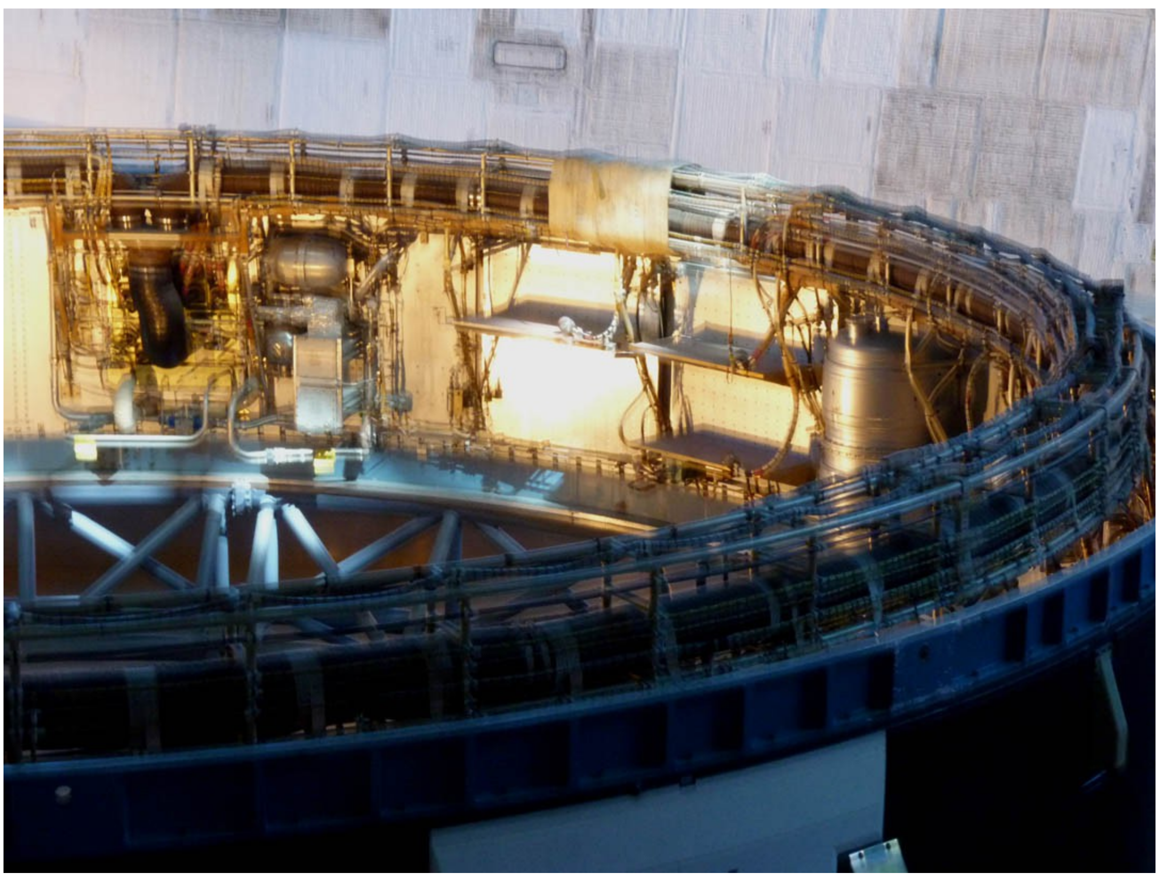
S-IV second stage

The second stage used six Pratt & Whitney Rocketdyne RL-10A3 engines which provided a vacuum thrust of 15,000 lbf each. The second stage was controlled by the guidance computer in the Instrument Unit. The job of this stage was to achieve a velocity of some 7600 m/s at a specified path angle. The S-IV stage was a 5.6 meter-diameter cylinder measuring 12.5 meters in length. The stage could burn for up to 470 seconds. The propellant flow rate was about 35 pounds per second. The engine’s ISP rating was 410.

The RL-10 engines burned liquid hydrogen and liquid oxygen, cyrogenic fuels with a very high energy content. They had been developed for the Centaur rocket, and were cutting edge technology. The cryogenic fluids needed special handling and safety procedures. The liquid hydrogen has to be cooled below –423 degrees f, or it boils. The Centaur was used as an upper stage for the Atlas and Titan rockets, and is still in production. It is also used in the upper stage of the Delta launch vehicle. It was developed at MSFC in the 1950’s. It first flew in 1962. The cyrogenic engine was a major improvement over the old kerosene or alcohol and LOX design. The stage was 40 feet long, and 18 feet in diameter. A single tank with a bulkhead to separate the fuel and oxidizer was used.

The Instrument Unit

The Instrument Unit (IU) was introduced with the Saturn-I, Block–II, unit SA-5, and used on the subsequent flights SA-6 through SA-10. These were designed at MSFC, and used for vehicle guidance, control, and sequencing, after the first stage completed its work. The IU's had their own telemetry, tracking, and power systems. The first model was a pressurized ring structure 154 inches in diameter, and 58 inches high. The large diameter matched the profile of the launch vehicle. Version two of the Instrument Unit was used on the Pegasus missions, SA-8, -9, and -10. This version was only 34 inches high and 21 feet in diameter. It was constructed of an aluminum honeycomb, less than an inch thick, and weighed 2,670 pounds. It was unpressurized, unlike the previous version. Subsequent Saturn-V vehicles used a third version. The IU was placed between the S-IV B second stage and the Apollo spacecraft payload. The IU was cooled by a water/methanol heat exchanger, and powered by batteries.



IU at the Smithsonian Air & Space facility at Dulles Airport, VA. Author phono.

The IU held the IBM LVDC digital computer, an analog computer for vehicle flight control, the ST-124 inertial guidance platform, accelerometers, and gyros. The sensor platform was a derivative of the one used in the V-2. The analog control computer took measurements of

angular changes and lateral acceleration, and commanded the engine gimbals to adjust accordingly.

ST-124

The ST-124 inertial guidance system was first used on the SA-5 vehicle. It was included on subsequent flights, including the Pegasus missions. According to the NASA Summary Report, "The flight tests indicated each guidance system performed to a high degree of accuracy." The ST-124 enabled closed loop guidance control for the entire powered flight. It was built by the Bendix Corporation.

The ST-124 platform used a four-gimbal system which permitted full freedom about all three vehicle axes. Three pendulous integrating gyro accelerometers were mounted on the ST-124 stabilized element. The range and cross range accelerometers were normal to each other in the local horizontal plane at launch with the range accelerometer directed down range. The altitude accelerometer was directed up and normal to the launch horizontal plane. The ST-124 platform was stabilized by three air-bearing, single-degree-of-freedom gyros mounted with the sensitive axes mutually perpendicular. The gyro axes were oriented such that some of the drifts were minimized.

LVDC

The ASC-15 Launch Vehicle Digital Computer was developed by IBM Corporation for the Titan missile. A modified version was used on the Saturn I Block-II. The computer used inputs from the ST-124 inertial platform to calculate trajectory and navigation. The processor was serial, using fixed-point data of a 28-bit word size. The hardware was built up from modules containing discrete components. Previous versions of the Saturn had used open loop control, with a carefully timed sequence of events. A preprogrammed sequence, depending only on time, used a 6-track magnetic tape recorder and sets of relays. The addition of the ASC-15 allowed closed-loop control for adaptive path guidance. The control update rate was 25 times per second. The computer clock was 2.048 MHz. The memory was up to 32 kilobytes of 28-bit words. Within these 28 bits were a 26-bit sign-magnitude data word, with two bits of error detection. Instructions were 13 bits long, with parity. Two instructions were packed in a memory word. Instructions had a 4-bit operation code, and a 9-bit address field. Memory used magnetic core technology, with delay lines for temporary storage. A separate hardware multiply and divide unit was included. Add time was 82 microseconds, multiply 328, and divide 656. The instruction rate was around 12,000 per second. The complexity of the unit was equivalent to over 40,000 transistors. It weighed 75 pounds, and required about 150 watts of power. It was programmed in assembly language.

The circuitry was triple-modular-redundant (TMR) with voting, and, in some critical case, quadruple redundant. The triple seven-stage instruction execution pipeline had voting circuitry at each stage. The published reliability number was 99.6% over 250 hours of operation, although

the unit was only required to operate for minutes in the early launches. There were 11 hardware I/O interrupts on the Saturn I-B models, including one for engine cut-off.

The computer system also did pre-launch self-test and supported mission simulation. Its primary purpose was booster guidance. In mission SA-6, one engine shut down prematurely, but the computer automatically adjusted the trajectory to compensate properly. 28-vdc power was supplied from alkaline silver-zinc battery packs, and the computer operated from four different voltage sources.

The digital computer had an associated Launch Vehicle Data Adapter (LVDA), which was an interface to the inertial platform, the command receiver and telemetry transmitters, the ground checkout computer (while on the launch pad), and other vehicle sensors, such as separation switches. The LVDA provided analog to digital conversion. It communicated with the LVDC over a 512 kbps serial interface. The LVDA input link from the RCA–110 ground computer was over a 14-bit data line. The LVDA weighed 214 pounds, and required 320 watts of power. Local storage of data in the LVDA was via glass delay lines. The LVDA had the ability to interrupt the LVDC.

Apollo spacecraft boilerplate

The Pegasus missions carried an Apollo spacecraft Command Module (capsule) with the launch escape system and a Service Module. These were built by North American Aviation in California. They had the same size, weight, shape, and center of gravity as the real article. The Pegasus payload was placed behind the service module, in an area that would later hold the Lunar Excursion Module for the moon flights. The boilerplate Apollo was a structural model with the proper mass properties, but no functionality. One separated from the Pegasus and second stage assembly, the Apollo capsule and service module went into a different orbit. The escape system was jettisoned after launch.

The Pegasus payload

The Pegasus missions were considered by NASA in February of 1962, and contracted to Fairchild Hiller Corporation. Design and development took place at their facilities in Bladensburg and Rockville, MD, with assembly in Hagerstown, MD. Pegasus was a secondary payload on the Saturn vehicle, with the primary payload being a boilerplate Apollo spacecraft. The Apollo boilerplate acted as a payload fairing for the Pegasus spacecraft, which was stored inside what would have been the Service Module. The Pegasus was a 3,200 pound satellite in low Earth orbit, designed to study micrometeoroid impacts, an area that was relatively unknown at the time. The satellite had large 95-foot wing panels that folded out from the satellite body, and included 116 detectors, a data and power system, and a telemetry and tracking system. A lot was learned from the missions besides the micrometeoroid environment. The Pegasus provided information on the thermal effects of surface coating in space, the susceptibility of electronics to

the radiation environment, the orbital thermal environment, flight dynamics characteristics, and many other factors.

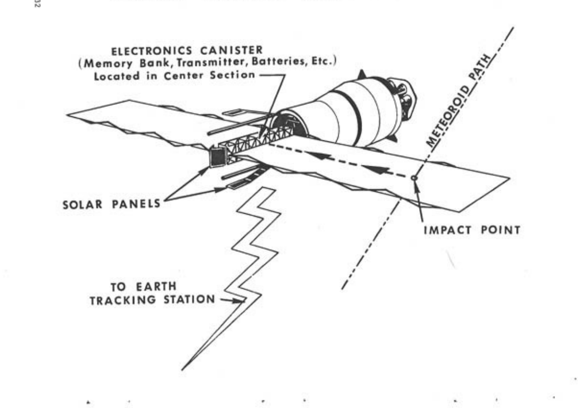
The Pegasus was a very large and heavy payload, but, with the Saturn, size and weight were not of much concern. Folded in launch configuration, the Pegasus was 17 feet, 4 inches high, 7 feet wide, and 11 inches deep. It was constructed of aluminum alloy. The large deployed wings contained penetration surfaces for the measurement of micrometeorite impact. The wings had a total surface of 2,300 square feet. The General Electric space environmental test facility at Valley Forge, PA was used for testing, due to the size of the spacecraft.

The original contract was for $6.5 million, but overruns were expected due to unknown factors at the time of contract signing. In the end, the program cost about $27,800.000. The prime contract number was NAS 8-5615.

The large spacecraft was transferred between the Fairchild facility in Maryland and the GE test facility in Pennsylvania in a special environment package, the Pegasus Transporter, by truck. The spacecraft in its container was flown from the Martin Company in Baltimore to the KSC on Aero Spacelines' Pregnant Guppy aircraft, a specialized transport built to handle large pieces of space flight hardware. The custom-built Guppy was a Boeing 377, piston-engined, passenger plane, heavily modified.

The Pegasus in orbit remained attached to the Saturn vehicles instrument unit and S-IV second stage. Overall, this assembly was 70 feet long and weighed about 23,100 pounds. The Pegasus itself weighed 3,200 pounds. In orbit, the Pegasus was visible to the unaided eye under favorable lighting conditions near dawn and dusk.

FIG. I-2. PEGASUS 'FINDS' A METEOROID



Before the first Pegasus flew, the Pegasus panels were tested by the Army at Fort Belvoir, VA, with hypervelocity (10-30,000 fps) impacts. Those tests confirmed that the impact velocity and

ambient pressure did not affect the panel’s performance. Simulated Saturn propellant tanks were also tested. Further impact testing was conducted by the Hayes International Corporation of Birmingham, AL.

The Marshall Space Flight Center under the direction of NASA's Office of Manned Space Flight was in charge of Saturn development. Marshall was also responsible for development of Pegasus under direction of the NASA Office of Advanced Research and Technology. The Kennedy Space Center was in charge of launching, and the Manned Spacecraft Center (now, JSC) provided the Apollo hardware.

Prime contractors included:

- First (S-I) stage, Chrysler Corp.

- S-I engines, North American Aviation's Rocketdyne Division.

- Second (S-IV) stage, Douglas Aircraft Co.

- Instrument unit, NASA's Marshall Space Flight Center, using major components supplied by IBM Corp, and others.

- Pegasus satellite, Fairchild-Hiller Corp.

- Apollo spacecraft, North American Aviation's Space and Information Division.

Development of Pegasus, named for the mythical winged horse**,** began in February, 1963. The NASA Office of Advanced Research and Technology directed the Pegasus Project, and had assigned project management responsibility to NASA’s Marshall Space Flight Center, Huntsville, AL.

Fairchild Hiller Corp. was the prime contractor. Sherman Fairchild had formed his Fairchild Aerial Camera Company in 1920, and this grew into Fairchild Aerial Surveys. He needed a better airplane for this work, and formed Fairchild Aviation in 1925. It went on to produce the famous C-119 Flying Boxcar cargo plane during World War-II. A modified C-119 snagged Discoverer XIV, the first midair recovery of a spacecraft returned from orbit. Fairchild Semiconductor was formed in 1957 with a group of Shockley Semiconductor employees. Fairchild Industries was formed in 1971, after the death of Sherman Fairchild.

Other industrial firms involved in significant aspects of the Pegasus development included:

- Adcole Corp., Cambridge, MA, solar aspect sensors.
- Barnes Engineering Co., Stamford, CN., horizon sensor system.
- Aluminum Co. of America, Pittsburgh, PA, structural extrusions.
- Di/An Controls, Boston, MA, system clock and core memory.
- Space Craft Inc., Huntsville, AL, beacon transmitter.
- United Electrodynamics Corp., Pasadena, CA, temperature sensor.

- United Shoe Machinery Corp., Beverly, MA, harmonic drive.
- G. T. Schjeldahl Co., Northfield, MN., detector panels.
- Bulova Watch Co., Flushing, NY, timer.
- Norden Division, United Aircraft Corp., Norwalk, CN, shaft encoder.
- Keltec Industries, Alexandria, VA, antenna, batteries and other components.
- Motorola, Scottsdale, AZ, diplexer, hybrid ring, low pass filter.
- RCA, Montreal, FM transmitter.
- AVCO Corp., Cincinnati, OH command receiver.
- Consolidated Systems Corp., Monrovia, CA. command decoder.
- App1ied Electronics Corp., Metuchen, NJ. PCM and PAM commutators.
- Space Technology Labs., CA, Electron spectrometer.
- General Electric Co., Philadelphia, PA, RYV-13. sealant and environmental testing.
- Corning Glass Works, Electronic Products Division, New York, glass resistors.
- Vinson Engineering, Van Nuys, C., actuator (back-up for the motor gearbox).
- Eastern Ai r Devices, Dover, NH, drive motor.
- Ion Physics Corp., Burlington, MA, design assurance radiation testing.
- Washington Video Productions, Washington, DC, technical documentation films.
- Hayes International Corp., Birmingham, A , design assurance particle impact testing.
- Dynatronics, Orlando, F., specialized PCM Data Readout Units (GSE).

The 11- by 16-inch wing panels were subdivided into 62 logic groups of from two to eight capacitors each. The capacitors are interconnected so that the satellite electronics package saw each logic group as one capacitor. A meteoroid hit on any panel was registered as a hit on the logic group in which that panel was located. Some capacitors on Pegasus I shorted in orbit, and it was necessary to remove logic groups; i.e., disconnect good or bad capacitors from the overall detection system. A new fusing arrangement was incorporated in the meteoroid detection system of Pegasus to fuse each capacitor individually. Before launch, the Pegasus satellites were known as A, B, and C.

A single malfunctioning capacitor left the other capacitors in the same logic group operating. When a malfunction occurred which was serious enough to warrant disconnection of the entire logic group, this could be done by ground command. The fusing arrangement worked successfully on Pegasus B and was installed on Pegasus C. The fuses could be blown by 50 milliamps. The ground command to blow a capacitor fuse could "heal" the capacitor instead of blowing the fuse, depending upon the cause of the short. Each capacitor "healed" in this manner was a bonus benefit. Each time a capacitor was penetrated by a meteoroid, the material removed by the impact was vaporized, forming a conducting gas which discharged the capacitor. The gas, or plasma, dissipated almost immediately and the capacitor recharged within three one-thousandths of a second. The recharge event was what was recorded.

If seen on the screen of an oscilloscope, the "blip" caused by a penetration and momentary discharge of the capacitor would be a sharp saw-tooth below the horizontal line. These blips were characteristic for each group of panels, providing a means of determining which group contained the penetrated panel.

When a panel was penetrated, several items of related information were recorded, including a cumulative count of hits classified according to panel thickness; an indication of the panel group penetrated; the attitude of the satellite with respect to both the Earth and the Sun, the temperature at various points on the spacecraft, the time at which each hit was recorded,; and the condition of the power supply and other equipment supporting overall spacecraft operation.

Various levels of impact energy were differentiated through the use of panels of three different thicknesses. Directional information was gained by using a combined solar sensor-Earth sensor system. The aluminum sheets of the wing assemblies were separated by a layer of polymer plastic, forming a capacitor. It was charged with 40 volts. There are capacitor panels on both sides of the wind assembly. There were a total of 416 separate detector panels. In addition, the spacecraft determined its attitude with respect to the Earth and Sun, suing Earth and solar aspect sensors. A backup mode was spin-stabilization.

The Pegasus electronic system registered meteoroid penetrations of panel groups and stored a record of panel thickness, group number, and time of penetration. Pegasus attitude and certain temperatures were recorded on a timed schedule. The storage for the data was a 30,080 bit magnetic core memory unit. This could nominally hold the data for 6 to 8 hours of operation. The memory was read-out and transmitted 6 times, for redundancy, then cleared. This required about 1.5 minutes.

Upon ground command, all recorded information was read out of the Pegasus storage system and telemetered to the ground. After read-out, the memory was cleared by command. A second beacon telemeter provided 11 housekeeping data and total meteoroid count data continuously throughout the mission. The spacecraft had two telemetry links for a total of 180 measurements. A digital command system provided for on-off control of various system components, circuit replacement, certain in-flight tests and other control functions. A solar cell-battery (nickel-cadmium) power supply provided all power for Pegasus for its projected one-year life. The batteries were recharged by the solar cells.

In addition, the Pegasus spacecraft carried a radiation environment detector, in the form of plastic scintillators that emitted visible light when impacted by energetic particles. The levels were set to 0.5 Mev and 2.0 Mev. They were modified for later flights to operate down to 100 Kev. These allowed a characterization of the radiation environment in Earth orbit.

The downlink telemetry was a 160-bit PCM word, with 13, 10-bit words of data, transmitted through the NASA system. Analog PAM format telemetry at the rate of 4 samples per second provided 60 housekeeping measurements such as temperature. The uplink command channel also used the NASA system, and had an instruction set of 70 commands for the spacecraft. Each Pegasus could be commanded separately, and this was used when all three were operational and on-orbit at the same time.

The Pegasus-B PAM telemetry was lost 3 days after launch. The cause was never determined, but the spacecraft had gotten wetted by rain during installation on the booster at the launch pad. In additional, the PAM and PCM equipment had failed the salt spray tests, but these worked in flight.

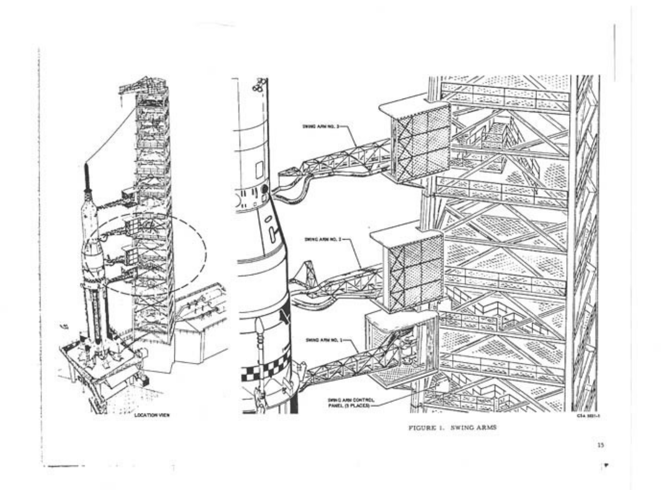
Data were telemetered to NASA's Goddard Space Flight Center on a 136.89 Megahertz carrier, using Pulse Amplitude Modulation (PAM) and Pulse Coded Modulation (PCM) schemes. The spacecraft was also large enough to be easily tracked by the Smithsonian Institution's Minitrack Optical system. There was also a beacon transmitter.

The Pegasus spacecraft was to detect meteoroids in the mass range of 10^{-7} to 10^{-4} grams, leading to an understanding of the on-orbit meteoroid environment in terms of density and direction. The measurements were taken between 500 and 800 kilometers. The detectors array used 116 capacitors of varying thicknesses over 185 square meters of area. Both real-time and stored data transmission were provided.

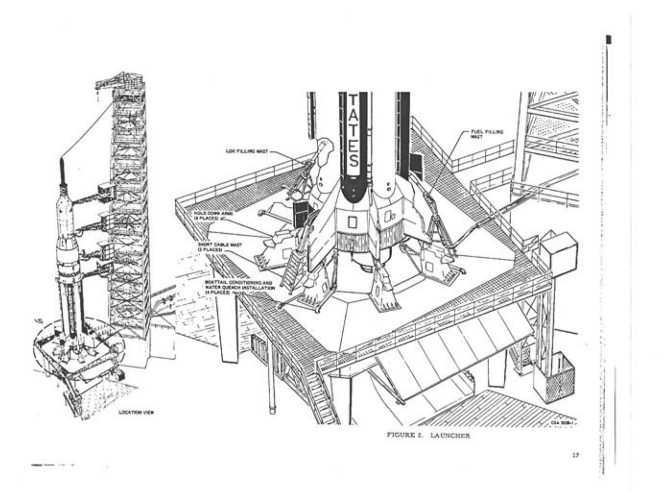
For the third flight, MSFC fabricated eight panels for a special engineering experiment and positioned them at comparable locations on each of the two wings of the spacecraft, four on each side. They were painted to make it easier to recognize them in orbit. The frame of the spacecraft was coated with luminous paint. There were six "coupons" on each panel, three on each side, for a total of 48 coupons. They are made of aluminum in three thicknesses: 16 at .008-inch or 8 mils thick; 24 at 16 mils or .016-inch; and eight at 32 mils or .032 inches. The coupons were fastened at two points to the main panels and could be removed quickly by an astronaut, and stored in Gemini or Apollo spacecraft compartments.

Launch Complex 37

The Saturn launch complex was a strong, intricate structure that also provided the ability to functionally verify the vehicle and payload before and briefly, during launch. There was a tower assembly with swing arms that rotated away from the vehicle at launch, and the umbilical cables disconnected. Three swing arm assemblies on the umbilical tower support the electrical cables, hydraulic and pneumatic lines, and air conditioning ducts that service the S-I stage, the S-IV stage, and the instrument unit of the Saturn vehicle during prelaunch operations. Swing arm number one, located between the 108 and 118 foot levels, serviced the S-I stage; number two, between the 128 and 138 foot levels, the S-IV stage; and number three, between the 158 and 168 foot levels, the instrument unit. Swing arm number two supported the S-IV stage propellant loading lines. The cyrogenics needed to be replenished as they boiled off in the Florida heat. At vehicle liftoff, the umbilical housings and connector plate disconnect from the vehicle and the swing arms rotate laterally out of the vehicle flight path. Solenoid-controlled pneumatic pressure actuates the umbilical. The swing arms also controlled the lines for propellant and oxidizer that are used to continuously top up the vehicle tanks.



At the launch pad, there were eight hold-down arm assemblies, operated by pressurized helium. These locked the vehicle to the pad until the launch commit criteria was met, which relied on achieving the proper thrust rating from the engines. If this was not achieved, the engines were shut down by command.



The launch pad assembly was the responsibility of the Marshall Space Flight Center, and its contractor, Chrysler Corporation, Space Division.

Launch Complex 37 covered some 120 acres and included two launch pads, A and B. Both pads were serviced by a 310-foot tall, 10 million pound service structure and a common blockhouse. Each pad at Complex 37 consisted of a metal launch pedestal with a 37-foot opening for escape of the rocket exhaust. A metal flame deflector was wheeled into place on tracks before launch to dissipate the exhaust

The countdown for the launch spanned two days. The first part of the checkout occupied the day before launch. The second part of the count begin on launch day at T-600 minutes. The last two minutes, 43 seconds of the count was controlled by an automatic sequencing system.

Complex 37 was built in 1962. Eight Saturn missions were launched from the B pad, but the A pad was never used. The facility was mothballed in 1972, and the service structures were scrapped in 1972. The structure of the pads still exist at KSC.

Fairchild operated the Pegasus Satellite Control Center at Kennedy Space Flight Center, Florida.

Tracking and Data Acquisition

The Pegasus missions required extensive ground tracking and data acquisition support. To meet this requirement, the Manned Space Flight Tracking Network along with certain elements of the Department of Defense Gulf and Eastern Test Ranges supported the spacecraft through its first five orbits, after which the Goddard Space Flight Center's STADAN (Space Tracking and Data Acquisition Network) assumed responsibility for monitoring and tracking the spacecraft

The GSFC was the operational nerve center of NASA's worldwide voice and data communications network, and provided tracking and telemetry data from the various ground stations to the other NASA Centers.

Goddard's MSFN real-time computing system determined orbital insertion conditions and provided the network with acquisition information during early phase of the mission. During the reentry period the real-time system was used for predictions and impact determination. For the Pegasus during deployment phase, GSFC**’s** Data Systems Division provided the network with orbital and prediction data derived from Minitrack tracking data.

Launch Control computer

The circa-1961 RCA-110 Computer Mainframe served as the checkout and launch control computer. It was located at the launch site. The software was developed at the Astrionics Lab at MSFC with support from the launch support team in Florida. The RCA-110A models had increased memory. The computer automated the entire preflight checkout process. There was a master computer in the blockhouse, and a slave computer at the launch pad. They were connected by a coaxial cable. The launch pad computer interfaced with the vehicle computer through an umbilical.

The RCA-100 was a 24-bit fixed-point process control machine. It was implemented in solid-state electronics, with a clock speed of 936 KHz, and 72 instructions. It supported four levels of priority interrupts, and had accumulators and index registers. There were also eight Input-Output registers. The add or subtract operation took 57 microseconds, a multiply took 728 microseconds, and a divide, 868 microseconds.

Memory consisted of 256 to 4096 words of core memory, later expanded. Secondary storage was provided by a magnetic drum assembly, rotating at 3,600 rpm, and providing 8.3 millisecond access to data. The drum held up to 51,200 words. Data were transferred to the computer at a 200 kilohertz rate. The computer unit was 82” x 34” x 105” in size, and required 5,000 watts of power at 220 volts.

Orbital Mechanics primer

This section gives a general and top-level explanation of orbital mechanics, so the comparable figures for the Pegasus missions may be understood. We'll start with **f=ma**, Newton's equation. We can apply this in the classical 2-body (satellite and primary) problem, for example, the Pegasus satellite and the Earth. When we try and factor in the effects of the Sun, Earth's moon, and other celestial body, we run into the three-body problem, which does not have a know solution. The best we can do is compute the orbit based on the two body problem, and include the effects of perturbations due to other objects.

In three dimensional vector form, we get 3 differential equations of the second order, with 6 parameters (degrees of freedom). If we know the position and velocity, we have the 6 parameters. At this point, I am going to skip over a semester of equations. Look up the details if you have an interest. (here is a good source: http://www.amsat.org/amsat/keps/kepmodel.html) The usual way to express these parameters for orbital mechanics is called the Keplerian elements. These are:

a – the length of the semi-major axis of the elliptical orbit.

e – the eccentricity; the shape of the orbit ellipse. If eccentricity is zero, we have a circle.

i = the inclination of the orbit to the primary.

longitude of the ascending node of the orbit, a horizontal orientation of the orbit to the reference frame, which is based on the primary.

argument of perigee (or peri-apsis), the orientation of the ellipse in the orbit plane.

And the last parameter, the Mean Anomaly at Epoch, defining the position of the orbiting body along the ellipse.

Johannes Kepler defined all of this in his studies of planetary motion. The inertial frame of reference is located in the primary. From these elements, others can be derived , such as the orbital period.

Here are the orbital elements for the SA-8 mission:

- Semi-Major Axis - 7,007 km
- Eccentricity - 0.01746
- Inclination - 31.763 deg
- Longitude of Ascending Node -158.87 deg (east)
- Argument of Perigee -133.85 deg.
- Orbital period, 97.29 minutes

Derived parameters were: Perigee Altitude 506.5 km, Apogee Altitude 751.2 km.

The Missions

SA-8

The SA-8 mission was to put the S-IV second stage, the Pegasus-B payload, and an Apollo boilerplate command and service module into a nominal orbit of 510 km by 754 km, with a mission lifetime of 2100 days. SA-8 left Launch Complex 37B at KSC on May 25, 1965, rising vertically for 9 seconds to clear the launch tower. It then began to roll at approximately 1 degree per second, and pitch over to the correct flight heading. The trajectory was designed to minimize the maximum dynamic pressure on the vehicle, expected at 68 seconds into the flight. The vehicle departed KSC on an azimuth of 105 degrees east of north, out over the Atlantic Ocean.

SA-8 was actually launched after SA-9, by the first Saturn-1 stage built by Chrysler. As they were running late, it was decided to launch SA-9 first with the last Saturn-I stage built at MSFC.

The mission goals were to achieve at least a one-year lifetime (3 year desired), to limit the maximum (apogee) altitude to 750 km, and to have a minimal amount of residual propellant (ullage) at engine cut-off. This was the fourth on-vehicle boilerplate test of the Apollo spacecraft, which was designated A-104. The boilerplate service module (BP-26) had additional instrumentation and a single reaction control engine assembly. There were two problems noted, neither very serious. Lox vapor blocked the light of sight to the ST-124 inertial platform alignment windows, and the gaseous hydrogen vent on swing arm 3 failed to separate at liftoff. The automatic swing arm rotation freed it.

A tilt arrest of 52.45 degrees was programmed at 138 sec after liftoff to ensure ample damping time for various propellant sloshing and transient motions in order to avoid premature cutoff and separation sequences. The separation sequence of events was commanded from a timer which was initiated by propellant level sensors.

After separation, tilt arrest was continued until 168 seconds after liftoff, allowing sufficient time for the LES tower and ullage casings to be jettisoned. The launch escape system had only one active motor, the jettison motor. This motor provided the capability of separating the LES from the command Module (CM) during an abort mode or normal flight.

The payload weight to orbit was 34,113 pounds (mass) for the Apollo, S-IV stage, and Pegasus. The apogee of the orbit was 506 kilometers, and the perigee was 745 kilometers.

After orbit insertion was achieved, there was a 3-minute venting period to purge LH2. Then, the second stage separated from the Apollo boilerplate (BP-26). The Pegasus wing deployment begins 60 seconds after separation, and took about one minute.

The first stage of the SA-8 (the S-I) nominally impacted the Atlantic Ocean at 25.7748 north, 21.3160 west, 965 km downrange.

The achieved orbit had a period of 95.2 minutes, an inclination of 31.7 degrees, and was in orbit for 5,275 days.

The following table shows the timeline of post-launch sequence of events, from engine ignition to separation of the second stage.

Event	
Ignition Command	Range Time (sec)
First Motion	- 3.29
Liftoff Signal	- 0.18
ASC- 15 "0" Time	0.078
Start Pitch Command	0.107
Start Roll Command	8.65
End Roll Command	8.66
Control Computer Gain Change	23.66
Enable S-I Level Sensors	110.11
Lock Modules (Tilt Arrest)	138.10
S-IV Ullage Rocket Fire	138. 36
Retro Ignition, Separation, Control Switch	148.82
Over	148.92
S-IV Hydraulic Accumulation Open	149.72
S-IV Ignition	150.62
Jettison Ullage/ LES	160.92
Introduce Guidance	166.69
Control Computer Gain Change	508.91
S-IV Cutoff (Guidance)	624.151
Insertion	634.151
S-IV and IU Tape Recorders Playback	724.8
S-IV and IU Tape Recorders Stop Playback	754.87
Close S-IV Auxiliary Non-Propulsive Vent	804.87
Initiate Pegasus Forward Restraint	805.87
Separation	805.97

After first six weeks in orbit, Pegasus had reported 73 penetrations by meteoroids. The Pegasus operated until August 29, 1968, when it reentered the atmosphere and burned on Sept 17, 1978.

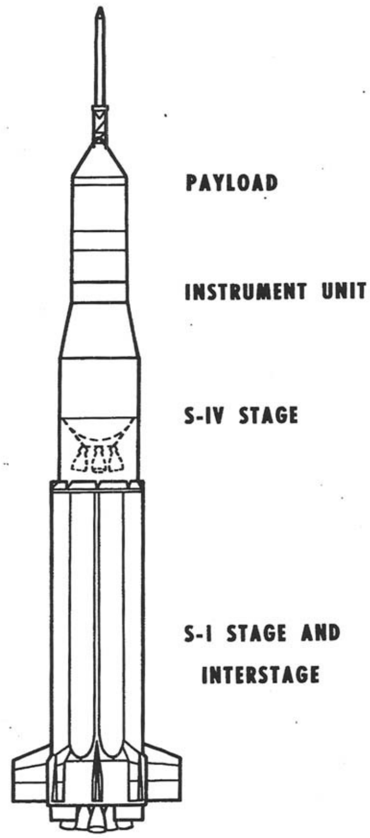


FIG. 2. SA-8 CONFIGURATION

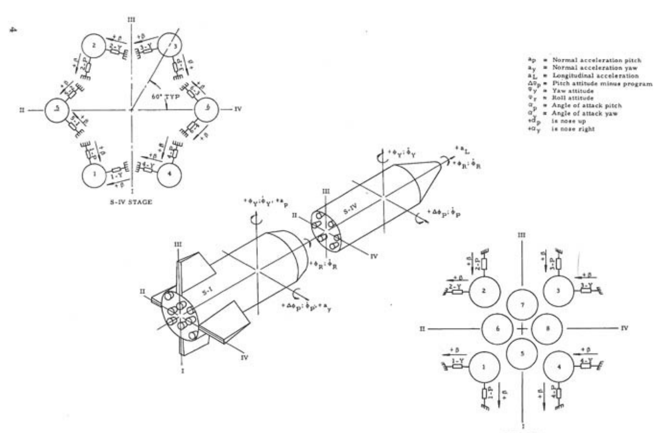
SA-9

SA-9 was launched Feb 16, 1965 at 9:37:03 EST. Ten minutes and 31 seconds after launch, the S-IV, IU, boilerplate Apollo and Pegasus-A were on orbit. The Apollo and shroud were separated, and the wing deployment of the Pegasus was completed in less than 5 minutes. The launch phase was observed by the radars at Antigua, Merritt Island, Grand Bahama, Bermuda, Patrick AFB, and Grand Turk. Orbital tracking was accomplished by STADAN. The achieved orbit was 496 kilometers by 744 km. As mentioned earlier, SA-9 was actually launched before SA-8, on the last Saturn-I assembled at MSFC.

SA-9 was the fourth Saturn I vehicle to be launched in a planned series of six Block II vehicle launches. The SA-9 vehicle overall length was 188 feet with a diameter of 21 feet 5 inches, excluding fins. The vehicle consisted of an S-I stage, S-IV stage, instrument unit, and a boilerplate Apollo Spacecraft with a Pegasus micrometeoroid experiment. Total mass on orbit was 33,895 pounds.

The S-I first stage measured 80 feet 3 inches long with a tank section diameter of 21 feet 5 inches, a maximum diameter (including fins) of 40 feet 8 inches, and a dry weight of approximately 103,000 pounds The stage was powered by eight Rocketdyne model H-1, fixed thrust liquid propellant engines developing a total nominal sea-level thrust of 1.5 million pounds.

The four inner engines were fixed in a 3-degree outward cant. For attitude control, the four outer engines were capable of being gimbaled up to 8-degrees. Four Aerojet model MB-I solid-propellant rocket motors provided first stage retro-thrust at S-I/S-IV separation.



SATURN SIGN CONVENTIONS

The S-IV second stage measured 41 feet, 5 inches long, with a dry weight of approximately 13,000 pounds. Stage propulsion was provided by six Pratt and Whitney model RL-10A3 engines, providing 15,000 pounds of thrust each. The engines were canted 6 degrees and were capable of being gimbaled up to 4-degrees for attitude control.

Propellant-ullage positioning was provided by four Thiokol model TX-280 solid-propellant rocket motors, designed to develop 4,800 pounds of thrust each for 39 seconds. These ullage rockets were jettisoned after S-IV engine ignition.

The IU, located between the S-IV stage adapter and the spacecraft, measured 2 feet, 10 inches long, with a diameter of 12 feet, l0 inches, and weighed approximately 2,650 pounds. It contained guidance and control equipment, four telemetry links, and the airborne portions of five tracking systems. Other systems contained in the IU included a power supply and distribution system, and the nitrogen supply for the gyro air bearings. Sensors mounted throughout the IU were used to detect inflight environmental conditions.

The boilerplate Apollo spacecraft (BP-16) included a command module, service module, spacecraft adapter, and launch escape system (LES) with a live jettison motor. The spacecraft weighed 18,600 pounds and measured 63 feet, 4 inches in length with a maximum diameter of 12 feet, 10 inches.

The Pegasus payload was located in the service module in an un-deployed state and was permanently mounted on the S-IV stage. The Pegasus collected information concerning the magnitude and direction of intermediate size meteoroids in the near earth-space environment. Prior to deployment, Pegasus measured 208 inches by 84 inches by 95 inches. When fully deployed, the wing panels extended a total of 96 feet.

A television camera, located in the spacecraft service module adapter section, was used to transmit real-time coverage of Pegasus status from liftoff through deployment. The Saturn space vehicle transmitted a total of over 1,284 measurements on 15 telemetry links. Thirteen of these links were carried on the launch vehicle, the remaining two on the spacecraft.

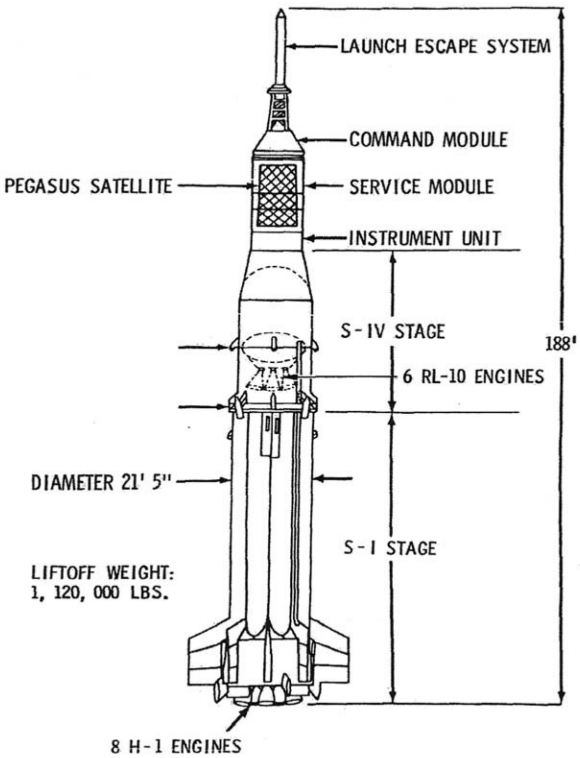
The primary mission objectives were:

- Earth orbit of Pegasus A (micrometeoroid experiment).
- Flight test of the closed-loop guidance system.
- Earth orbit of the spent S-IV stage, IU and payload as a unit.

Secondary mission objectives were:

- Demonstration of the physical and flight compatibility of the launch vehicle stages and spacecraft.
- Demonstration of launch vehicle and various research and developmental instrumentation

SATURN SA-9 VEHICLE



Sketch of Saturn with Pegasus payload at launch.

NATION'S THIRD LARGEST SPACECRAFT

The following is a chronological summary of events and preparations leading to the launch of SA-9

S-IV arrived via aircraft and offloaded to Hangar AF	October 30, 1964
S-I and IU-9 arrived via barge at Hangar AF dock area and off-loaded.	November 3, 1964
S-I erected and secured.	November 10, 1964
S-I umbilical connected.	November 12, 1964
S-I power applied.	November 13, 1964
Apollo Spacecraft Service Module and adapter arrived via aircraft	November 19, 1964
and off-loaded to Hangar AF	November 20, 1964
S-IV and IU erected	November 23, 1964
S-IV umbilical connected.	November 24, 1964
Power applied to IU	November 25, 1964
S-I RF checks completed.	December 8, 1964
Power applied to S-IV stage.	December 14, 1964
IU RF checks completed.	
Electrical mate of S-IV, IU, and	December 16, 1964
S-I completed and power applied	December 17, 1964
S-I/IU Power-Transfer Test completed	December 21, 1964
Launch vehicle EBW functional test comp	December 29, 1964
Launch Sequence Malfunction Test comp.	December 30, 1964
Pegasus A (payload) arrived via aircraft	
Pegasus A hangar checkout started	
ST-124 installed	January 5, 1965
Pegasus hangar checks completed	
Pegasus A erected on launch vehicle	January 12, 1965
Command module erected on launch	January 13, 1965
Vehicle.	January 14, 1965
Pegasus electrical mate with launch vehicle completed	January 15, 1965
Space vehicle EBW functional test completed.	January 21, 1965
Space vehicle RF checks completed.	
Plug Drop and Swing Arm Overall Test completed.	January 22, 1965
S-I, S-IV Ordnance Installations completed	January 25, 1965
All Systems Overall Test completed	February i, 1965
Countdown Demonstration Test completed.	February 5, 1965
Terminal countdown started	February 12, 1965

Propellant Loading

RP-I fuel was loaded into the S-I stage on February 10, 1965. LOX and LH2 were loaded during the launch countdown. RP-I was adjust-level drained in the launch countdown on February 16, 1965. The sequence of operations during the launch countdown was as follows:

- Precool filled S-I stage with partial load (20%) LOX for leak check
- Loaded S-IV stage with LOX to 98%.
- Precool filled S-I stage LOX to 20% then fast filled to 95%.
- Replenished both S-I and S-IV stages with LOX.
- Slow filled S-IV stage LHp to 15%.
- Fast filled S-IV stage LH_ to 95%.
- Slow filled S-IV stage LH2 to 99.25%°
- Replenished S-IV stage LH2
- Adjust-level drained RP-l from S-I stage.

RP-I Operations.

Propellant loading was a meticulous operation, both because of the hazards involved, but also to ensure the proper amount of propellant was in the tanks at the moment of ignition. RP-I was loaded on February 10, 1965. The S-I stage was slow-filled by individual component operation at a rate of 200 gpm to a 15% level, as indicated by the loading computer, for leak checks of both the S-I stage and ground system. Upon completion of the leak checks RP-I was loaded by the automatic fast-fill sequence at a rate of 2000 gpm to 98% full, as indicated by the fuel loading computer. Slow fill was automatically initiated and a pressure correction of +325 psi was dialed into the computer. The system continued filling the stage at a rate of 200 gpm until the 100% indication was received. Adjust-level drain was initiated with a correction factor of + 125 psi. Because of undetermined flight-loading requirements, the stage was then replenished to a +325 psi correction in the loading computer. Both density and loading systems were within tolerances, and no problems were encountered during loading operations. Subsequent loading table selection necessitated recalibration of the loading computers and draining of the RP-1 transfer line section between the S-I stage fill-and-drain valve and the adjust-level valve. At T-135 in the Countdown Demonstration Test (CDDT), RP-I was replenished to a 320 psi correction in anticipation of performing an adjust-level drain later in the count. At T-10 an adjust level sequence was initiated with a correction factor of +150 psi dialed into the loading computer. All systems were within tolerance with a stage bulk-fuel temperature average of 75°F (LOX not loaded).

At T-10 minutes in the launch countdown, the S-I stage RP-I level was adjusted to a set pressure correction of +015 psi. The deviation between the temperature calculated from the percent nominal density (as indicated by the density computer) and the average of fuel tank temperatures (as recorded) varied. Sequence was initiated at T-5'50", and the mast purge was initiated at T-4 30". The lift-off signal closed the booster line valve, but mast purge was lost at approximately 3 seconds after lift-off due to the solenoid valve being shorted by water. No problems resulted from loss of the mast purge. All systems operated satisfactorily.

LOX Operations

LOX loading during the launch countdown was performed as follows: pre-cool was initiated at T-374' 40", and the 18% leak-check loading was completed at T-330' 16". At the 15% level, S-I stage replenish was activated, and verified to 20%. Both the S-I stage and the LOX transfer system were leak checked. At T-221' 30" S-IV LOX precool was initiated. The S-IV main-fill pre-cool valve was open for approximately 9 minutes 30 seconds. An indication of adequate stage pre-cooling was obtained, after which the S-IV main fill was started and an indication of 98% full was recorded at T-198' 33". S-I LOX pre-cool was initiated at T-155' 20" with the LOX level computer set at approximately 15%; however, pre-cool was continued until the tank level reached 20%. A +400 psi correction was dialed into the computer and S-I main fill was initiated. At 65% full signal, LOX replenish pre-cool was initiated. At S-I 95% full signal, fast fill was terminated. Automatic replenish of both the S-I and S-IV stages was interrupted when the replenish tank-pressure-complete sensing switch opened at 157 psig, causing the system to revert to a storage-tanks-pressurized-complete status. The cause of the malfunction was determined to be the inability of the replenish tank pressurization system to keep up with the combined S-I and S-IV replenish requirements. The condition was further aggravated by an initially small replenish tank ullage volume. The replenish tank was topped to 28,000 gallons prior to start of sequence. The pressure switch was overridden, and S-I/S-IV LOX replenish was re-initiated satisfactorily. At T-10 minutes, a final S-I LOX set pressure correction was dialed into the computer.

LH Operations

LH loading was initiated at T-80 minutes when the transfer system pre-cool was imitated. Slow fill of the S-IV stage was established at T-72 minutes and was continued until a 15% full indication was obtained at T-55 minutes. Main fill was initiated and the stage was loaded to 95% full at T-41 minutes. Automatic replenishing was initiated at T-40 minutes. Only one malfunction occurred in the propellant transfer systems. The LOX replenish-tank-pressure complete switch dropped out at 157 psig. This malfunction did not delay loading operations nor halt the countdown. Power was applied to the RCA 110A computer at 2145 EST, February 15, 1965. Computer preparation was complete at approximately 2245 EST, and the operational programs were inserted to support SA-9 launch checkout. Launch occurred at approximately 0937 EST, February 16, 1965, and computer participation was terminated at T+30 seconds. Post-test operations began immediately thereafter and were completed within 2 hours. The computer was energized for a total of approximately 14 hours in support of the launch.

SA-9 was the fifth engineering test of the radar altimeter. The altimeter acquired reliable data from 175 to 240 sec, 420 to 490 sec, and 520 to 631 sec. Although not as continuous as on SA-7, the altimeter data provided a very good altitude trend and was used extensively in stabilizing the vertical component of the reference trajectory.

The S-IV payload at orbit insertion (631.659 sec) had a space-fixed velocity 0.3 m/s less than nominal, a perigee altitude of 496.5 km and an apogee altitude of 745.0 km. The estimated lifetime of the orbiting vehicle was approximately 1188 days, which was 62 days less than the nominal lifetime.

During its first three months in orbit, Pegasus recorded multiple meteoroid penetrations. Though useful results were obtained with .00l5 inch thick panels, the data obtained with .008 inch thick and .016 inch thick panels was not fully satisfactory because of a number of difficulties which were experienced in the operation of the detection system.

A new capacitor fusing arrangement was used on the second Pegasus after short circuits in the Pegasus I detection system hampered the capabilities of that satellite. This new system was working well after one month. It provided the ability to disconnect a single malfunctioning capacitor detector while leaving other capacitors in the same group of panels working. Thirty-six capacitors on Pegasus were found to be working improperly during the first four weeks and were disconnected by ground command to prevent a drain on the satellite's power supply. Of these 36 capacitors, four were isolated and disconnected.

Pegasus-2 returned data until August 29, 1968. It reentered the atmosphere on November 3, 1979.

SA-10

The SA-10 mission lifted off at 8:00 am local time on July 30, 1965, from the Kennedy Space center. It was the final Saturn I configuration vehicle to be flown. It consisted of the S-I stage, the S-IV second stage, the Instrument Unit (IU), an Apollo spacecraft boilerplate model (BP-9), and the Pegasus-C. It was the final flight of the Apollo boilerplate, and the final Pegasus flight.

The S-IV second stage of the launch vehicle had arrived at Cape Kennedy on May 9. The booster came by the Navy barge *Compromise* on May 31**.** The booster stage was too big to go from MSFC to KSC by rail, road, or air. An earlier collapse of a lock at the Wheeler dam below Huntsville on the Tennessee River had trapped the custom Saturn barge *Palaemon*. The Compromise got stuck in the mud of the Indian River at the Cape, and delayed the planned launch.

The vehicle had a firing azimuth of 95.2 degrees east of true north. It was targeted to an altitude of 289 nautical miles. The flight planning and parameters were similar to that of the previous Saturn-Pegasus missions. There were high winds (to 17 knots) noted before launch.

This was the third flight of a prototype model of the IU. Besides placing the Pegasus in orbit, the mission provided valuable power-flight data on the various vehicle stages and for the boilerplate Apollo vehicle as well. It verified the propulsion and flight control systems, the separation sequence, and closed loop guidance.

Another potential use of the third Pegasus experiment was announced in NASA Press Release 65-232 in July 1965. This was to attempt to return to Earth samples of the meteoroid punctured metal, with hopefully captured micro-meteoroids. The Press Release states the purpose,

“This flight's primary purpose is to add information on the frequency of meteoroids to be encountered in near-Earth environment, for use in the design of future manned and unmanned spacecraft. The information was vitally needed with the increased emphasis on larger, long-life spacecraft, and the mission of the three-flight Pegasus program was to provide data necessary t o determine the magnitude of the meteoroid hazard.”

“The engineering experiment consists of 4-8 aluminum sub-panels or "coupons" attached to Pegasus which could be quickly unhooked by an astronaut on an EVA and carried back to Earth in a Gemini or Apollo capsule. NASA officials emphasize that no decision has been made for an astronaut to rendezvous and retrieve the panels.” Keep in mind, this was before any manned Apollo Capsule had flown.

“Although numerous experiments have been conducted in space, no materials punctured by meteoroids have been returned so far. Meteoroids are the countless small particles of matter flying in space at great speeds. When they enter the Earth's atmosphere, they burn -- as meteors - and those that reach the ground are known as meteorites.”

At the time of the third Pegasus launch, the previous two Pegasus spacecraft were still on-orbit, returning data. Additional data on the micrometeorite environment was still coming in from Explorer XXIII, launched in 1964.

Unlike the two previous vehicles, the tenth Saturn I did not carry a camera to provide pictures of Pegasus deploying in space. The vehicle did carry a television camera mounted on the outside of the booster at the top, pointing back toward the engines. Its purpose was to observe the booster's plume or exhaust shape which expands greatly as the vehicle encounters less dense atmosphere. The image from the camera was recorded on video tape at Cape Kennedy and was used later in plume shape measurements and flame attenuation studies.

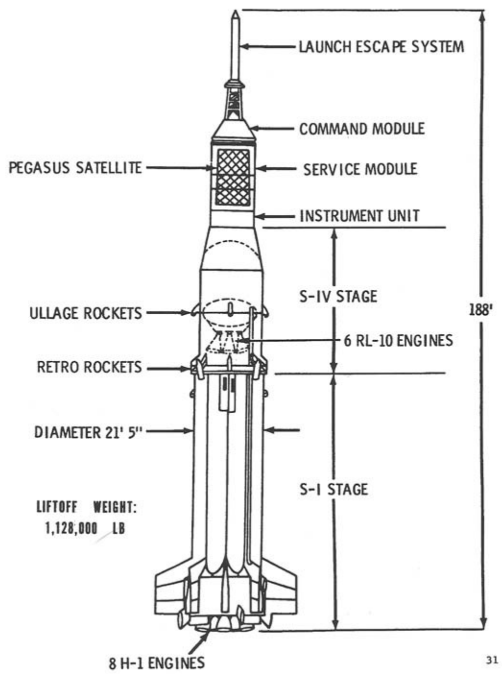
There had been a concern over high vibration levels noted on the SA-8 and SA-9 flights, but these were not noticed on SA-10. These were measured with a total of 54 vibration and three acoustic sensors distributed over the vehicle stack. The data were received on the ground and put on magnetic tape for transfer to MSFC for analysis. Mechanical vibrations can be damaging to structure, and these were carefully scrutinized. Most of the mechanical vibration came from the combustion chambers, with some contribution from the turbine gearboxes. All of these were noted to be within specification. This verified the vehicle and Apollo capsule vibration and acoustic environments during launch.

Nominal Sequence of Events for SA-10
Time of Event (From Liftoff)

0.0	Lift off
9.0	Initiate Roll and Pitch Simultaneously
14.2	Terminate Roll
137.7	S-I Stage Propellant Level Sensors Enabled
138.0	Tilt Arrest
141.7	S-I Stage Level Sensor Signal
143.52	Inboard Cutoff (S-I Stage)
149.52	Outboard Cutoff (S-I Stage)
150.22	Ullage Rocket Ignition(S-IV Stage)
150.32	Separation, Immediately Followed by Retro
152.02	Ignition (S-I Stage)
162.32	S-IV Main stage Ignition
168.0	Jettison Ullage Rocket Casing and LES
595	Initiate Active Guidance
632.085	Signal from Sequencer to Arm LOX
642.085	S-IV Stage Main Engine Cutoff
	End of Powered Flight

The SA-10 Saturn vehicle was launched from Cape Kennedy on July 30,1965 at 8:00:00 Eastern Standard Time. Approximately 10 minutes after launch the S-IV stage, instrument unit, Apollo boilerplate and the Pegasus Meteoroid Technology Satellite were inserted into orbit, a total mass of 34,438 pounds. The Apollo and shroud were first separated from the S-IV/IU and Pegasus

FIG. I-1. SATURN SA-10 VEHICLE



combination, and wing deployment on the Pegasus was completed 4.5 minutes after orbit insertion. SA-10 was the sixth and last flight test of the Saturn I, Block II vehicle which included an active S-IV stage. This was the fifth flight test with guidance in closed loop during the S-IV powered flight.

The S-IV payload at insertion (640.252 sec) had a space-fixed velocity 0.7 m/s (2.3 ft/s) less than nominal, a perigee altitude of 528.8 km (285.5 nm) and an apogee altitude of 531.9 km (287.2 nm). The estimated lifetime of the S-IV/PEGASUS C orbiting vehicle was approximately 720 days, which was 5 days less than the nominal lifetime.

Nominally, the first and second stages would drop into the Atlantic. However, the probability of these extending and striking the African land mass were calculated. The probability of injuring a person in Angola was calculated at 3.4x10–6, and for Madagascar, 2x10–7. In addition, the issue of having to destruct the vehicle shortly after launch was carefully studied. This was the point where the maximum amount of fuel was involved. Premature engine cut-off was also of concern, The third Pegasus operated until August 29, 1968, and reentered the atmosphere on August 4, 1969.

Subdividing the impact probabilities for individual countries:

Land Area	Dwell Time	Impact Probability
Angola	2.8	7.6×10^{-4}
Rhodesia & Nyasaland	1.5	4.1×10^{-4}
Bechuanaland	.1	2.6×10^{-5}
Mozambique	.3	8.1×10^{-5}
Madagascar	.2	5.3×10^{-5}

The probability of injuring a person downrange can be determined in the following manner:

$$P_{IP} = P_I \times \frac{N}{L_A} \times A_L$$

where

P_{IP} = probability of injuring a person

$\frac{N}{L_A}$ = population density of country

A_L = lethal area

The probability of injuring a person, by overflying land is:

$$P_{IP} = 4.7 \times 10^{-6}$$

The probability of injuring a person, subdivided by Nation:

Nation	P_I	N/L_A (Per Sq. Mi.)	P_{IP}
Angola	7.6×10^{-4}	25	3.4×10^{-6}
Rhodesia & Nyasaland	4.1×10^{-4}	12	8.8×10^{-7}
Bechuanaland	2.6×10^{-5}	1	4.7×10^{-9}
Mozambique	8.1×10^{-5}	25	3.6×10^{-7}
Madagascar	5.3×10^{-5}	21	2.0×10^{-7}

BAD AREA STUDY

Example calculation of landing impact probabilities.

Conclusion

The Pegasus Program had involved the launch of three Saturn vehicles with boilerplate Apollo capsules, and the Pegasus satellites. The amount of useful information gained for the eventual Apollo manned missions to the moon was immense. Before Pegasus, virtually nothing was known about the near-Earth micro-meteoroid environment. The Pegasus missions showed the feasibility of manned flight to the moon.

Beyond the Pegasus missions, there were operational flights tests of the Saturn-V launch vehicle, and on-orbit tests of the Apollo capsule, leading to the lunar missions.

Glossary

ABMA – Army Ballistic Missile Agency, Redstone Arsenal, Huntsville, Alabama.

AIAA – American Institute of Aeronautics and Astronautics.

AMD – Aircraft Missiles Division, Fairchild Hiller, Hagerstown, MD.

AOMC – Army Ordnance Missile Command – 1958, Redstone Arsenal, JPL, WSPG.

Apogee – farthest point in the orbit from the Earth.

ASC –Advanced Spacecraft Computer, by IBM, for Titan launch vehicle.

ARPA – Advanced Research projects Agency.

Astrionics – electronics for space flight.

BP – boilerplate. Mechanical model.

Cyrogenic – pertaining to very low temperatures.

DoD – Department of Defense.

DTM – dynamic test model, for structural tests.

Gimbal – pivoted support, allowing rotation about 1 axis.

Gpm – gallons per minute.

GSFC – NASA Goddard Space Flight Center, Greenbelt, MD.

Gyro – device to measure angular rate.

H1 – Rocketdyne engine, used on Saturn-I first stage.

ICBM – Intercontinental Ballistic Missile.

IBM – International Business Machines Company.

Interrupt – signaling mechanism for input/output devices on a computer.

IRBM – Intermediate Range Ballistic Missile.

ISP – specific impulse. Measure of efficiency of rocket engine. Units of seconds.

IU – Instrument Unit.

JPL – Jet Propulsion Laboratory, Pasadena, CA.

JSC – Johnson Space Center, Houston, Texas.

Jupiter – ICBM, 3-stage. Developed by von Braun Team.

Kbps – kilo (10^3) bits per second.

Kev – kilo electron volts, measure of energy of a particle.

KSC – NASA Kennedy Space Center, launch site, Florida.

Lbf – pounds, force.

LC-37 – Launch Complex – 37 at KSC.

LEM – lunar excursion module.

LEO – low Earth orbit.

LES – Apollo Launch Escape System.

Lox – liquid oxygen, boils at -297 F.

LVDA – Launch Vehicle Data Adapter.

LVDC – Launch Vehicle Digital Computer.

Mev – million electron volts, measure of energy of a particle.

MINITRACK – “Minimum Trackable Satellite “ U. S. satellite tracking network, 1957.

MMC – Micrometeoroid Measurement Capsule, original name of Pegasus.

MSC – Manned Space Center, Houston, TX. Renamed JSC.

MSFC – NASA Marshall Space Flight Center, Huntsville, AL.

m/s – meters per second.

NASA – National Aeronautics and Space Administration.

NORAD – North American Air Defense.

NRL – Naval Research Lab, Washington, DC.

NTIS – National Technical Information Service (www.ntis.gov).

PAM – pulse amplitude modulation.

PCM – pulse code modulation.

Perigee – closest point in the orbit from the Earth.

POGO – oscillation in liquid-fueled rocket motors that can lead to failure.

R&D – research & development.

Redstone – Army missile developed by the von Braun team. Used for Mercury manned flights.

Redstone Arsenal – Army R&D facility in Huntsville, AL. Later became NASA MSFC

RP-1 – rocket propellant one, highly refined kerosene.

SA – x – Saturn-Apollo – flight x.

SAO – Smithsonian Astrophysical Observatory.

S-IV – second stage of Saturn 1 rocket.

STADAN – Space Tracking and Data Acquisition Network.

Titan – ICBM and NASA/USAF launch vehicle.

TM – Technical Manual.

Ullage – residual fuel or oxidizer in a tank after engine burn is complete.

V-2 – German World War-II missile developed by the von Braun Team.

Vdc – volts, direct current.

WSMR – White Sands Missile Range, New Mexico.

References

Rocket Development

ANSER Corporation *A Historical Look at United States Launch Vehicles, 1967-present*, Arlington, VA, 1994, ANSER. ASIN: B000GOZZ14.

Baker, M. E., & United States. *Redstone Arsenal: Yesterday and Today*. Redstone Arsenal, Ala: Secretary of the General Staff, U.S. Army Missile Command, 1993.

Bitzer, J. A., Woerner, T. A., *Army Ballistic Missile Agency* (U.S.), Redstone Arsenal (Ala.). (1997).

Bitzer, John A. and Woerner, Ted. A. *A4-Fibel* (English translation), Redstone Arsenal, 1957, ISBN 1-894643-14-3.

Brzezinski, Matthew *Red Moon Rising: Sputnik and the Hidden Rivalries that Ignited the Space Age*, Holt Paperbacks; 1st ed., 2008, ISBN 080508858X.

Committee on Science and Astronautics, U.S. House of Representatives, Transfer of the Development Operations Division of the Army Ballistic Missile Agency to the National Aeronautics & Space Admin, GPO, Washington, DC, 1960, ASIN: B001J5BIH4,

Dunar, Andrew J. and Waring, Stephen P. *Power to Explore: A History of Marshall Space Flight Center 1960-1990*, CreateSpace Independent Publishing Platform, 2012, ISBN-1478266465.

Gruntman, Mike *Blazing The Trail: The Early History Of Spacecraft And Rocketry* (Library of Flight Series), AIAA, 2004, ISBN- 156347705X.

Hardesty, Von, Eisman, Gene and Khrushchev, Sergei *Epic Rivalry: The Inside Story of the Soviet and American Space Race*, National Geographic, 2007, ISBN 1426201192.

Lennick, Michael *Launch Vehicles Heritage of the Space Race*, 2006, Apogee Books, ISBN 1-894959-28-0.

Payne, J. J. *Summary of Impact Testing for NASA Project Super,* 1966, AEDC-TR-66-97, Fort Belvoir, Defense Technical Information Center.

Sattersfield, Paul H. *Historical Monograph, Army Ordnance Satellite Program*, 1958, Army Ballistic Missile Agency, ASIN: B0007HDV8Y.

Stakem, Patrick H. *The History of Spacecraft Computers from the V-2 to the Space Station*, 2011, PRB Publishing, ASIN B004L626U6.

The Development of Ballistic Missiles in the United States Air Force 1945-1960, CreateSpace Independent Publishing Platform (June 22, 2012), ISBN-10: 147811844X.

V-2 and the von Braun team

21st Century Complete Guide to U.S. Army Redstone Arsenal History: Missiles, Rockets, von Braun, Space History (CD-ROM), 2002, Progressive Management; 1st ed, ISBN-1193182830X.

Dornberger, W. *V-2*, 1960, Ballantine, ASIN: B001O4M1MQ.

Dungan, T. D. V-2: *A Combat History of the First Ballistic Missile*, Westholme Publishing, 2005, ISBN- 1594160120.

Huzel, Dieter. K. *Peenemunde to Canaveral*, 1962, Prentice-Hall Greenwood Press Reprint, May 12, 1981, ISBN-0313229287.

NASA, World Spaceflight News, *Wernher von Braun: His Life and Work from German Missiles to the Saturn V Moon Rocket - An Expansive Compilation of Authoritative NASA History Documents and Selections,* Progressive Management, 2012, ASIN: B007FFY48C.

Neufeld, Michael, *von Braun, Dreamer of Space, Engineer of War*, Vintage; Reprint edition, 2008, ISBN- 0307389375.

Neufeld, Michael, *The Rocket and the Reich*, Peenemunde and the Coming of the Ballistic Missile Era, 1995, Smithsonian, 0-02-922895-6.

Nicaise, Placide D. *Huntsville and the von Braun Rocket Team*, 2003, ASIN B00AX2GL4E, 2003.

Ordway, Frederick I., Sharp, Mitchell P. *The Rocket Team* 1979, Crowell, 0-690-01656-5.

Bergast, Erik *Wernher von Braun*, 1996, National Space Institute, ISBN 0-917680-01-4.

Transfer of von Braun team to NASA. Hearing before the NASA Authorization Subcommittee of the Committee on Aeronautical and Space Sciences, United States Senate, Eighty-sixth Congress, second session, on H. J. Res. 567, a bill to effect immediately the transfer of the Development Operations Division of the Army Ballistic Missile Agency to the National Aeronautics and Space Administration, U.S. Govt. Print. Off. (1960), ASIN: B007HV5XX4.

von Braun, Wernher, Ordway, Frederick I., III, Durant, Fred *Space Travel: A History: An Update of History of Rocketry & Space Travel*, 1985, ISBN-0061818984.

Zaloga, Steven J. *V-2 Ballistic Missile 1945-52,* 2003, Osprey, ISBN 1841765414.

Redstone Missile

Bullard, John W. *History of the Redstone Missile System*, 1965, ASIN: B00ACXXQAQ.

Chrysler Corporation Missile Division, Army Ballistic Missile Agency, *This is Redstone Missile Weapon System,* Periscope Film LLC, 2012, ISBN- 1937684806.

Jupiter Missile

The Other Missiles of October: Eisenhower, Kennedy, and the Jupiters, *1957-1963*, The University of North Carolina Press, October 1, 1997, ISBN- 0807846473.

Titan missile

Berhow, Mark *U S Strategic and Defensive Missile Systems 1950-2004*, Osprey Publishing, 2005, ISBN- 1841768383.

Launius, Roger D. (Ed) and Jenkins, Dennis R. (Ed) *To Reach the High Frontier: A History of U.S. Launch Vehicles*, The University Press of Kentucky; 1st ed, 2002, ISBN- 0813122457.

Van Riper, A. Bowdoin *Rockets and Missiles: The Life Story of a Technology,* The Johns Hopkins University Press, 2007, ISBN- 0801887925.

Saturn-I

Astrionics System Handbook, Saturn Launch Vehicles, MSFC No. IV-4-401-1, IBM No. 68-966-0002, Nov. 1968.

Aviation Week and Space Technology, Sept. 16, 1963, pp 54-63.

Aeronautics and Astronautics, AIAA, June 1964, pp. 25, 30-38.

Aviation Week & Space Technology, July 20, 1964 pp 80-81.

Bilstein, Roger E. *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*, 1980, NASA SP-4206. ISBN 0-16-048909-1 http://history.nasa.gov/SP-4206/sp4206.htm

Chapman, R. A. *Saturn I Block II Guidance Summary Report*, NASA TM-X-53398, Feb. 1966, MSFC.

Decher, Rudolf, *The Astrionics System of Saturn Launch Vehicles,* NASA TM – X-53384, Feb. 1, 1966, NASA/MSFC, Astrionics Laboratory.

Haeusserman, W. “Guidance and Control of Saturn Launch Vehicles,” July, 1965, AIAA Paper 65-304, presented at AIAA Second Annual Meeting, San Francisco, CA.

Instrumentation System Description (S-IU-202 thru 204/501-503) Saturn IB/V Instrument Unit Technical Manual, MSFC No. III-5-509-1, IBM 65-966-0021, NASA CR-123904, IBM Corp. June 1966.

Lange, Oswald H. *Space Carrier Vehicles, Design, Development, and Testing of Launching Rockets* (Advances in Space Science and Technology). Academic Press, 1963. ASIN: B0007E6LXO.

Lowery, H. R. *Saturn Instrument Unit Command System*, NASA TM X-53350, Oct. 1965.

NASA Facts, Launch Vehicles, NASA SP-10, Vol. II, No. 5 and Supplement, 1965.

NASA, *Space, the New Frontier*, Government Printing Office, 1967. (available, ASIN:B006HXHY80).

Missiles and Rockets, 7th Annual World Missiles/Space Encyclopedia, pp. 18.

Powell, J. T. "Saturn Flight Instrumentation," Nov. 1964, ISA Journal, Vol. II, No. 11, pp 51-63.

Range Safety Aerodynamic Characteristics of Saturn I, Block I1 Vehicle Consisting of the SA-5, SA-6, and SA-7, M-AERO-AA, July 19, 1963.

Saturn I Summary, NASA/MSFC, N66-23597.May 1966.

Saturn 1B and Saturn V Computer Programs, Software Status Report, NASA TM-X-729C1, TR-612, Rev. 13, July 5, 1972, NASA/JSC.

Space Exploration USA, pp. cover, 54, 59.

Thomason, H. E. A *General Description of the ST-124-M Inertial Platform System,* NASA TN D-2983, Sept. 1965.

Vaughan, W. W. "Wind Profile Envelopes for Selected Flight Azimuths," Office Memorandum No. M-AERO-G-53-63, March 28, 1963, Cape Canaveral, Florida.

From the author's personal collection:
MSFC drawings, size J drawing, 1/20 scale

- SA-8, 9, 10 Layout & Human Engineering Section 1963, 10M03686.
- Assembly Layout, S-I Stage SA/8 1963, 10M03575.
- Assembly Layout Payload. Saturn SA8,9,10 1963, 10M03590.
- Assembly Layout, S-IV stage, SA 8,9,10 1964 10M03707.
- Assembly layout, Saturn SA-8,8,10 1963 10M03686.
- Main Service Points, Saturn SA-8,9,10 1961, 10M03574.
- Misc. painting and lettering diagrams.

Pegasus

Bannister, T. C.; Eby, R. J. *Pegasus Thermal Design*, MSFC, Nov 1, 1966, Document ID 19660030608.

Barkley, M. B., Jr.; Holland, R. L.; Rodrique, F. A. MPR-SAT-FE-65-14, 9.24,65, *Results of the Tenth Saturn I Launch Vehicle Test Flight*, Saturn Flight Evaluation Working Group, MSFC, Sept. 16, 1969, NASA-TM-X-53924.

Clifton, S.; Naumann, R. J. *Pegasus Satellite Measurements of Meteoroid Penetration*, February 16 - December 31, 1965, MSFC, Dec 1, 1966, Document ID 19670003479.

Dozier, J. B. *Meteoroid Data Recorded on Pegasus flights*, MSFC, Nov 1, 1966, Document ID 19670002057.

Dozier, J. B.; Heller, G. B.; Shelton, R. D. *Secondary Measurements by Pegasus*, MSFC, Nov 1, 1966, Document ID 19670002058.

Final Report, *Pegasus Program*, October 1965, Fairchild Hiller, Space Systems Division. NTIS N68-8704.

Graff, C. *The Electrical Power system for the Pegasus Satellite*, MSFC, Jan 1, 1967, Document ID 19670021261.

Jex, D. W.; Johnson, C. L.; Naumann, R. J. *Calibration of Pegasus and Explorer 23 detector panels*, MSFC, Sept 1, 1969, NASA-TR-R-321.

Johnson, W. G. *Operational aspects of Project Pegasus*, MSFC, Nov 1, 1966, Document ID 19670002056.

Linton, R. *Thermal Design Evaluation of Pegasus*, MSFC, Dec 1, 1966, Document ID 19670002627.

NASA Facts, *Pegasus,* N65-30685, Vol. II, No. 15, 1965.

Naumann, R. J. *Pegasus satellite measurements of meteoroid penetration, February 16 - July 20, 1965,* MSFC, Dec 1, 1965, Document ID19660003949.

Scientific Results of Project Pegasus Interim Report, MSFC, July 3, 1967, NASA-TM-X-53629.

Snoddy, W. C. *Pegasus Thermal Experimental Results*, MSFC, Jan 1, 1966, Document ID 19670015317.

SA-8

Dalton, C. C. *Cislunar Meteoroid Impact and Puncture Models with Predicted Pegasus Satellite Punctures,* Jan 13, 1965, Document ID 19650007940.

Haussler, Jonathan B.; Benson, Robert H. *Saturn SA-8/Pegasus B Postflight Trajectory*, MSFC, Aug 2, 1965, Document ID 19920075312262.

MPR-SAT-FE-65-6, 11/25/64, R*esults of the Eighth Saturn I Launch Vehicle Test Flight*, Saturn Flight Evaluation Working Group, MSFC.

Weichel, H. J. *SA-8 Flight Test Data Report*, NASA/MSFC, NASA TM X-53308, 1965.

SA-9

Benson, R. H.; Haussler, J. B. MPR-SAT-FE-65-6, 7/27/65, *Results of the Ninth Saturn I Launch Vehicle Test Flight*, Saturn Flight Evaluation Working Group, MSFC, Apr 30, 1965, Document ID 19650016419

Haussler, Jonathan B. and Benson, Robert H. *Saturn SA-9/Pegasus A Postflight Trajectory*, NASA/MSFC, NASA TM X-53251.

SA-9 Vehicle and Launch Complex Functional Description, N65 23189, April 1964, HEC-D042, Volume VII, Chrysler Corporation, Space Division,

SA-9 Launch Vehicle Measuring System and Associated Checkout GSE Description, Dec. 30, 1964, SP-172, N65-85054, NASA/KSC/Measuring Branch.

SA-9/Apollo Firing Test Report, NASA/KSC, K-PA-0002, March 10, 1965.

Space Vehicle SA-9 Telemetry System, TM X-53352, NASA/MSFC, Oct. 25, 1965.

SA-10

NASA Press Kit 65-232 July 21, 1965, Final Pegasus/Saturn will carry detachable panels.

Haussler, Jonathan B and Benson, Robert H. *Saturn SA-10/Pegasus C Postflight Trajectory*, Sept 1965, MSFC, NASA TMX-53340.

SA-10 Flight Mechanical Summary, NASA/MSFC, July 13, 1965, NASA TM X-53293.

Solmon, G. W. and Leonard, E. L. *Range Safety Data for Saturn SA-10*, NASA/MSFC, Range Safety Data Report #4-65, June 17, 1965.

Vibration and Acoustic Analyses, Saturn SA-10 Flight, NASA/MSFC, NASA TM X-53366, Dec. 8, 1965.

Apollo

Godwin, Robert *Project Apollo: The Test Program, Volume 1,* Collector's Guide Publishing, Inc. 2006, ISBN-1894959361.

Logsdon, John M. *John F. Kennedy and the Race to the Moon*, Palgrave Macmillan, 2010, ISBN- 023011010X.

Orloff. Richard W. and Harland, David M. *Apollo: The Definitive Sourcebook*, Springer Praxis Books/Space Exploration, Springer; 1st ed., 200), ISBN-10: 0387300430.

Orbital Mechanics

Logsdon, Tom *Orbital Mechanics: Theory and Applications*, 1997, Wiley-Interscience, ISBN 0471146366.

Prussing, John R and Conway, Bruce A. Orbital Mechanics, 1993, Oxford University Press, ISBN- 0195078349.

Sources

http://ntrs.nasa.gov/

http://www.ibiblio.org/apollo/index.html

Encyclopedia Astronautica, www.astronautix.com/

http://www.allpar.com/history/military/missiles.html

http://space.skyrocket.de/doc_sdat/pegasus.htm

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16-bit Microprocessors, History and Architecture, 2013 PRRB Publishing, ASIN B00D5ETQ3U.

Apollo's Computers, 2014, PRRB Publishing, ASIN B00LDT217.

The Architecture and Applications of the ARM Microprocessors, 2013, PRRB Publishing, ASIN B00BAFF4OQ.

Earth Rovers: for Exploration and Environmental Monitoring, 2014, PRRB Publishing, ASIN BOOMBKZCBE.

Embedded Computer Systems, Volume 1, Introduction and Architecture, 2013, PRRB Publishing, ASIN B00GB0W4GG.

The History of Spacecraft Computers from the V-2 to the Space Station, 2013, PRRB Publishing, ASIN B004L626U6.

Floating Point Computation, 2013, PRRB Publishing, ASIN B00D5E1S7W.

Architecture of Massively Parallel Microprocessor Systems, 2011, PRRB Publishing, ASIN B004K1F172.

Multicore Computer Architecture, 2014, PRRB Publishing, ASIN B00KB2XIQD.

Personal Robots, 2014, PRRB Publishing, ASIN BOOMBQ084K.

RISC Microprocessors, History and Overview, 2013, PRRB Publishing, ASIN B00D5SCHQO.

Robots and Telerobots in Space Applications, 2011, PRRB Publishing, ASIN B0057IMJRM.

The Saturn Rocket and the Pegasus Missions, 1965, 2013, PRRB Publishing, ASIN B00BVA79ZW.